ANTICLINAL MOUNTAIN RIDGES IN CENTRAL WASHINGTON.[1]

THE recent revival of interest in the Basin range type of mountain structure has caused the review of many of the data bearing upon that subject. Mountain ridges of the same type were early described by Professor I. C. Russell[2] as occurring over an area somewhat removed from the Great Basin. Similarity of climate and the consequent presence of desert conditions east of the Cascade mountains produce a certain resemblance of central Washington to that region farther south, and the great expanse of basalt lava also renders it natural to consider this area as in a way the continuation of the northern portion of the Great Basin. More questionable, however, is the assumption that the type of mountain uplift commonly believed to be so persistent in the Great Basin is likewise characteristic of central Washington.

A critical consideration of the earlier descriptions of the structural features of central Washington is deemed essential at the present time for two reasons. In the first place, the published results of the geologic reconnoissances, containing as they do the first descriptions of the area, possess the authority that naturally goes with priority. Thus these statements of geologic observation and inference come to be generally accepted and cited by writers who have occasion to refer to the region;[3] and this general acceptance prevails, although quite different descriptions of the area have been published which are based upon later geologic studies of the same area.[4] It is therefore desirable to state distinctly the opposition of later field observations to the statements based upon earlier work. This direct

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] "A Geological Reconnoissance in Central Washington," *Bull. U. S. Geol. Surv.*, No. 108, 1893.

[3] An example of this can be found in the *Third Report, Bureau of Soils*, U. S. Dept. of Agriculture, p. 392, 1902.

[4] *Water Supply and Irrigation Paper, U. S. Geol. Surv.*, No. 55, pp. 23, 24, 1901.

comparison of observations must be made that the reader may have the evidence before him. In the second place, this statement of the disagreement between the results of earlier reconnaissance and later detailed mapping is important in that it may contribute something in the way of suggestion to the broader problem of determining the origin of the Basin ranges. In the solution of such problems, the observations, largely physiographic in character, made in the course of a rapid reconnaissance, may be found later not to be in accord with the geologic data secured during a careful survey of the same area or a portion of it. The methods employed in reconnoissance work are of necessity quite different from those possible in the mapping for folio publication, when a topographic base map is available and the area is thoroughly traversed. Thus, the plea for a rehearing of the evidence does not concern the witnesses so much as the different conditions under which their observations were made.

The Ellensburg quadrangle in central Washington has been mapped geologically by the writer and Mr. Frank C. Calkins, and the results of that survey are incorporated in Folio No. 86 of the *Geologic Atlas of the United States*. The area is one of considerable geologic interest, as it lies in the zone intermediate between the Cascade mountains and the Great Plain of the Columbia. It is natural, therefore, that related as this region is to both of these distinct topographic provinces, its geologic study should yield results bearing upon the structure of both the mountains on the west and the plateau on the east. The area is likewise of interest as the one visited earlier by the reconnaissance geologist and as including many localities the descriptions of which apparently contain the basis of generalizations concerning the prevalence of the Basin range type in central Washington. In the following pages such descriptions will be cited, followed by comment based upon the results of the later work. For the full discussion of the geology and physiography of this quadrangle the reader must be referred to the Ellensburg folio, since the present article can contain only such points as bear directly upon this discussion.

A brief statement of the geology may serve to introduce the

discussion of the structural features. Only two important formations are involved, and both extend eastward to the Columbia. The older is the great series of Miocene basalts, measuring several thousand feet in thickness, and this is overlain by Miocene sediments 1,500 feet thick in the best-observed section. To these two series the names "Yakima basalt" and "Ellensburg formation" have been given. Reference will also be made to the Wenas basalt, which consists of one or more thin lava flows interbedded with the lower portion of the Ellensburg formation, unimportant except as it often affords more exact datum planes for the determination of structure. Topographically the region is one of moderate relief, and the general absence of erosion subsequent to the latest deformation of the region is a result expressive of the aridity of the climate.

The first recognition of the Basin range structure in central Washington is given by Professor Russell in these words:[1]

> All of the formations mentioned in the preceding section were originally spread out in essentially horizontal sheets, but since the youngest member in the series was laid down they have been broken into blocks, and the blocks tilted and upturned so as to form prominent mountain ridges with horizontally floored valleys between. A structure has thus been given to the beds on which depends nearly all of the present topographic diversity of the region. . . . .
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> Briefly stated, the main structural features in our field are (1) narrow, sharp-crested ridges having a prevailing east-and-west trend, due to the upheaval of the borders of orographic blocks; (2) broad and comparatively gentle north-and-south elevation, produced apparently by an arching of the strata, parallel to and probably of the same date as the much greater uplift forming the Cascade mountains; (3) regions where the rocks have been but little disturbed and now form plains and valleys.

The author distinguishes monoclinal ridges and monoclinal folds. Of the former he states:

> The prevailing and most typical structure has been produced by the breaking of the strata and the upturning of the beds on one side of the lines of fracture. The fragments, more or less regular, into which the rocks have been broken are termed orographic blocks. (P. 28.)

The monoclinal folds are thus described:

[1] *Op. cit.*, pp. 28–31.

Besides monoclinal ridges there are other types of mountains in the region traversed which are not so simple in their structure. These are long, narrow ridges which were formed by an arching of the strata without breaks. (P. 29.)

In a later publication[1] the structural features of this area are again described:

The monoclinal structure so characteristic of the western portion of the region known as the Great Plain of the Columbia, and of its southern extension in the Great Basin, due to the tilting of fault-blocks, was found to extend to the mountains on the west. As one approaches the Cascade range from the east, the tilted blocks, the upturned edges of which are short mountain ridges, become of larger size, and form the immediate foothills of the main range. This merging of the structure characteristic of the interior basin with the mountains bordering it on the west, so far as my own observations extend, is more pronounced in central Washington than elsewhere.

A third reference to this region is made in a later report by the same author:[2]

Again, to the east of the portion of the Yakima valley just referred to, as described in a previous report, there are several mountain ridges, such as the two bordering Moxee valley on the north and south — known, respectively, as Selah ridge and Yakima ridge — and Satas ridge, which forms the northern border of the tilted plateau termed Horse Heaven. Each of these ridges is due mainly to the tilting of a block of the earth's crust, capped with basalt, along lines of fracture. This series of faults, and perhaps in part of monoclinal folds, trends nearly east and west, and some of them cross the Columbia, as, for instance, the break on the north border of Saddle mountain.

Five ridges of the topographic type mentioned above cross the Ellensburg quadrangle, and, by way of comment on the general statements given above, these ridges may be considered separately, quoting as far as possible any specific mention that may have been made of them in the earlier reports.

The southernmost of these five ridges is Yakima or Atanum ridge, mentioned in the preceding paragraph. In the earlier report[3] this ridge is more accurately described as having "an arched structure throughout" and belonging to the class of "monoclinal folds," but later (p. 52) the possibility of "a break along portions of the northern base" is mentioned. The observations

[1] *Volcanoes of North America*, 1897, p. 248.

[2] "A Preliminary Paper on the Geology of the Cascade mountains in Northern Washington," *Twentieth Annual Rept., U. S. Geol. Surv.*, Part II, p. 138.

[3] *Bull. No. 108*, p. 29.

made by Mr. Calkins and the present writer along this east-west ridge convinced us that the structure is that of a broad arch, somewhat unsymmetrical, in that on the northern limb the dips are steeper than on the opposite side, and for short distances the strata are even overturned. This anticlinal structure in the basalt flows is well exhibited at Union Gap, where the Yakima river has made a steep-sided cut, a mile in length and 800 feet in depth, across the ridge.

The next ridge to the north is Selah ridge, also mentioned above. In the earlier description (p. 29) it is stated that here "the arch is broken longitudinally and the ridge assumes the faulted character described in the preceding paragraph," *i. e.*, it is a "monoclinal ridge." A more detailed description is given on a following page (p. 54):

> The structure of Selah ridge is too complex to be described intelligently without the aid of map and detailed section, but these are not to be had on account of the lack of an accurate survey. The ridge is an exception to other similar uplifts in the same region, for the reason that it changes from a monoclinal ridge at the west, where the dip is toward the north, to a monoclinal ridge at the east having a gentle slope to the south. The general form of the ridge is that of a long, narrow arch, broken at the west end by a fault on the south side, and by another fault on the north side, for the greater portion of its length.

On the preceding page the structural relations at Selah gap are considered somewhat more fully:

> In the west end of the ridge, separated from the main portion by the deep transverse canyon cut by Yakima river, the east side of the fold is wanting. It may have been cut away by the Naches, which flows along its base, but more probably was carried down by a fault which may have been continuous with a break to be seen on the south side of the ridge and east of the Yakima. There is also a cross-break running north and south which determined the course of the Yakima river. This is shown by the lack of correspondence in the dip of the light-colored John Day beds (Ellensburg formation) occurring on the sides of the canyon.

The detailed study given to this locality when it was mapped afforded no reason for considering that Selah ridge possesses a structure more complex than other ridges of the vicinity. There appears to be no necessity for dividing it "into sections having various structures." It is true that farther west where it merges

into the basalt plateau it is monoclinal in part, but there it is hardly a distinct ridge, becoming such only as it assumes an anticlinal structure. In the vicinity of Yakima river, where the descriptions quoted above apply, this anticlinal structure is pronounced, and on the edge of Selah gap the anticline is seen to be flat-crested with steep sides. For two miles west of Yakima river the south side of the fold—erroneously termed the east side in the last quotation—is cut away by Naches river, while similar cliffs have been produced east of Selah gap on both sides of the ridge by meanders of Yakima river. That these steep escarpments in no wise indicate faulting seems evident by the presence of efficient agents in these rivers at the base of the cliffs, but is demonstrated by the presence of a remnant of the southern limb of the fold south of Naches river. Here the Ellensburg sandstone occurs with a steep dip to the south, just where this portion of the anticline should be found, while east of Selah gap, immediately beyond Yakima river, the fold is also perfectly preserved. The presence of the Wenas basalt interbedded with the sandstone makes it possible to work out the structure with considerable certainty. As regards the "cross-break running north and south," this appears to be explained as a slight sag or fold, the anticline pitching differently on the two sides of Selah gap. In brief, then, the assumption that this ridge is due in any degree "to the tilting of a block of the earth's crust capped with basalt along lines of fracture" seems unwarranted by observed facts. The anticlinal structure is plainly exhibited, and in this respect the ridge is no "exception to other similar uplifts in the same region."

The ridge next to be treated is Cleman mountain, an uplift which, like those described above, crosses the Yakima, but is most prominent ten to fifteen miles farther west. This has been described as follows:[1]

> The Naches, for a score of miles at least above the mouth of Tiaton creek, flows through a deep canyon, bounded on the east by the precipitous face of a long, uplifted mountain mass having the topographic form of a great fault scarp, in which the inclination of the strata is northeastward. The

[1] *Bull. No. 108*, p. 65.

country about the upper portion of the Naches was only seen from a distance, however, and may have a more complete structure than is here suggested.

Here again the later field study has afforded conclusive evidence that the Cleman mountain anticline is complete, except for a distance of six miles along its southern slope, where a huge landslide has pushed into the canyon of Naches river below. However, it is along the lateral escarpment facing this landslide area that the best exposures of the structure are to be had.

Umptanum ridge succeeds Cleman mountain on the north, Wenas valley separating the two. North of this in turn is Manastash ridge, known also as the Beavertail hills. The reconnoissance description of this region follows:[1]

> The rocks on the head waters of Wenas creek are Columbia lava, broken and upturned in fault scarps, which merge into a general region of uplifts to the west, but become separated and well defined in traversing the desert country to the east. The ridges thus found agree in their principal features with nearly all the east and west ridges in Yakima and Kittitas counties. One of the lines of east-and-west faulting between Wenas and Kittitas valleys is marked by Umptanum ridge, which presents its bold escarpment to the northward. North of this, again, are the Beavertail hills, which are also a monoclinal uplift.

Umptanum ridge is perhaps the highest of these east-west ridges where it is crossed by Yakima river. The perfect arch of the ridge at Umptanum gap exposes a thickness of Yakima basalt exceeding 2,000 feet. The anticlinal structure is most evident, the fold being unsymmetrical, with the northern dips steeper. If any faulting is present, it must be of the nature of displacement on the plane between two sheets of basalt, but in any event, judging from the excellent section seen in Umptanum gap, faulting is of minor importance. Along the northern face of the ridge farther west there is a prominent outcrop of black basalt making a scar somewhat suggestive of a bedding fault. At another point, however, an even more prominent feature of this sort was seen in section, and the observation was conclusive as to the absence of any faulting. Thus, on the evidence of detailed study, the assertion is confidently made that in no

[1] *Ibid.*

respect is Umptanum ridge of the nature of a faulted monoclinal fold.

Manastash ridge likewise exhibits the anticlinal structure, unsymmetrical, and again with the steeper dips on the north limb. In the vicinity of Yakima river there is a fault present, as shown in the areal distribution of the formations. This fault, however, produces no scarp, and indeed crosses slightly the topographic axis of the ridge, showing the impossibility of its having any part in the elevation of the ridge. In fact, this fault belongs to a period of deformation antedating the uplift of these ridges to their present elevations. Throughout the region the orographic history has been more complex than is indicated in this article, where only those facts are cited which bear upon the points in question.

Farther east the Manastash ridge uplift unites with others to form Saddle mountain, which is cut through by Columbia river at Sentinel bluffs. The structure of Saddle mountain was described by Professor Russell as follows:[1]

> Saddle mountain, as previously mentioned, belongs to the series of monoclinal uplifts due to faulting, which extend eastward from the foothills of the Cascades. This long, narrow, sharp-crested ridge is perhaps the most remarkable of these uplifts, as it extends farther east than any of its companions and clearly reveals its structure where the Columbia has cut through it.
>
> It is there a well-defined monoclinal ridge, dipping sharply southward and presenting a bold scarp to the north. The dip of the strata of basalt of which it is composed corresponds with the gently sloping southern side. The line of fracture is on the north side of the ridge, and the steep northern face is a fault scarp. Toward the eastern end the fault scarp decreases in height and finally dies out, and the John Day beds pass over and conceal the Columbia lava. The dip of the strata on each side of the ridge toward its eastern end becomes about the same, showing that the fault passes into a fold.

Through the kindness of Mr. Frank C. Calkins, the following quotations are made from his description of the same locality from the manuscript of a water-supply paper now in preparation:

> The north face of Saddle mountain, where it overlooks the lower stretch of Crab creek . . . . suggests faulting in a very striking way. . . . . It is obvious that we must have here either a normal fault with the downthrow to the north or a sharp flexure, the downfolded portion having been removed by erosion, leaving only the nearly horizontal strata on either side. . . . .

[1] *Ibid.*, p. 96.

On the west side of the Columbia, opposite the mouth of Crab creek, the continuation of the mountain is bounded on the north, not by a cliff, but a steep slope. The mountain shows no outcropping horizontal ledges, but rising through the mantle of soil sloping back on the spurs and forward in the gulches can be traced the outcrop of one or more especially resistant beds of black lava, having a dip a little steeper than the slope. . . . . At another point twenty miles east of the mouth of Crab creek, the slope of the mountain was examined again and a similar state of things observed. . . . . The evidence demonstrates that there is here a sharp flexure and not a fault.

While the fact is not proven beyond doubt, I believe that this flexure, observed both east and west, was once continuous along the entire front of Saddle mountain, that the cliff along lower Crab creek is the product of erosion, and that the flexure is here concealed below the sediments in Crab creek bottom.

This citation of conclusions as to the orography of central Washington based upon reconnoissance observations and their comparison with the results of later and more detailed field work is believed to be justified by the result gained. Further evidence as to the true type of uplift is presented in the accompanying structure sections, Fig. 1. These are drawn to scale, and the structural features indicated are based upon dips observed along the line of section, and upon the general form of the different anticlines as exposed in the Yakima canyon section. The opportunity for direct observation of structure afforded in these gaps cut by Yakima river is exceptional and entitles the structure sections to considerable credence. The use of the scale 1 : 125,000 without vertical exaggeration renders the relief much less prominent than it appears to be in the field, but it is believed that a more accurate conception of structure can be obtained from these sections than from many drawn to illustrate the Basin range type, in which, as the author states, "the vertical scale is exaggerated and no attempt is made to represent the structure of the orographic blocks."

The type of deformation existing in central Washington is of interest in that enough is known of the geologic history to state the amount of load under which the rocks were flexed. Mention has been made of the two periods of uplift. In the earlier, which is believed to have been during either late Miocene or early Pliocene, the Yakima basalt may have been covered by 2,000

feet of Miocene sediments, the thickest section of the Ellensburg formation measuring 1,600 feet. Subsequent erosion, however, removed the Ellensburg, and even some sheets of the Yakima basalt over considerable areas, so that the later deformation was of the nature of flexing at essentially the present surface. This uplift began probably in the Pliocene and continued long enough so that even now erosion has not essentially modified the ridges of deformation. The exception to this statement is found in the water gaps of the Yakima and Naches rivers, in which cases

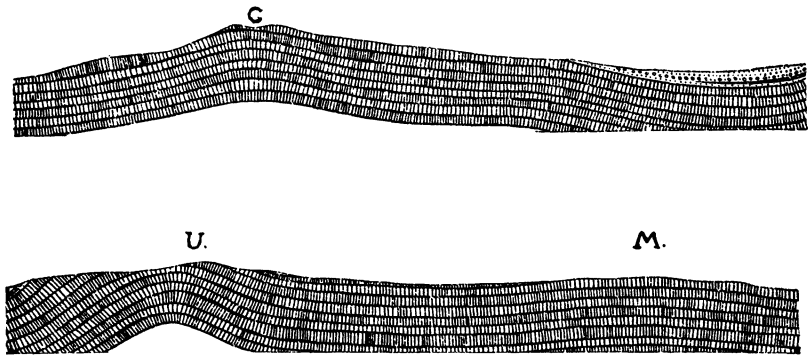

FIG. 1

streams coming from the more humid region to the northwest have possessed sufficient corrosive power to withstand the deformation forces and maintain their right of way across the uplifted ridges. The mechanics of such surface deformation would alone constitute an interesting subject of investigation. It is evident to any observer that a series of basaltic flows in which the columnar jointing is so common a feature would act quite differently under deforming forces than more rigid formations. The type of deformation found here is that termed by Van Hise[1] "joint folds." One distinction must be kept in mind, namely, that the joints in the Yakima basalt are not the product of the deformation forces, but owe their origin to contraction in the cooling lava. During the later deformation these thousands of joints may have been opened sufficiently to allow the production of the broad flexures of the basalt sheets. Adjustment along the planes between suc-

[1] VAN HISE, JOUR. GEOL., Vol. V, p. 191.

cessive lava sheets, as well as between the vertical columns, must reasonably be expected to have been important in whatever flexing took place. Such displacements, however, were at no place observed, and are doubtless on a minute scale, although of considerable importance in the aggregate.

A consideration of the cause of deformation of the nature described here would lead to the discussion of a much broader question. It would involve the origin of the Cascade range, the uplift of which is believed to belong to the same period as the production of these east-west ridges. Such a discussion will be in order after the results of detailed mapping over larger areas of the Cascade mountains are in hand. It may, however, be in accord with the purpose of this paper to take exception to certain assumptions as to origin with which the geologist apparently sometimes enters such a field. An example follows:[1]

> The arches were raised by a force acting from below upward, and not by lateral pressure which forced the strata into ridges and troughs, as is common especially in the Appalachian mountains.

This distinction between the supposed monoclinal structure with faulting and the more common type of deformation appears to be based in large part upon certain *a priori* hypotheses developed in the course of work farther south, viz.: tilted orographic blocks are expressive of lateral extension rather than lateral compression, and the region is one characterized by depression as well as by fracturing. Therefore, central Washington, like southern Oregon, was at once considered as characterized by deformation which involves extension rather than compression. It is now suggested that such assumptions are not the only ones that can be made to account for the facts. A glance at the structure sections will show this assumption of extension to be unsupported by the field evidence. The occurrence of overturned strata on the limbs of folds is, moreover, forcibly suggestive of some degree of lateral compression, while the fact that the Yakima cuts below the floors of several of the transverse synclinal valleys may be considered good evidence that these valleys are not sunken areas, but have simply been uplifted less than the bordering ridges.

[1] *Bull. No. 108*, p. 29.

The search for a force to supply this supposed upward pressure involves further difficulty (p. 29).

> Just what the action was which produced these arches it is difficult to determine. It is possible that volcanic rocks, escaping in a molten state through fissures in lower beds, raised the Columbia lava and superimposed beds into arches. In the continuation of the ridge cut through at Union gap, which forms the south wall of Moxee valley, molten rock forced up from below escaped through fissures in the Columbia lava, but raised the lighter beds above into a long, narrow ridge. In this instance the intruded lava has been clearly exposed by the erosion of a longitudinal valley along portions of the crest of the uplift.

In another place (p. 54) Selah ridge is cited as another possible occurrence of uplift by intrusion. "There are also reasons for suggesting that the scoriaceous basalt at the base of the section may have been a subsequent intrusion." In a careful study of the basalt section at the latter locality with a view to substantiate the earlier observation, the present writer failed utterly to find any reason for supposing any of the basalt intrusive. Both here and in the other locality cited the extremely scoriaceous character of the basalt was observed, but was taken by him to indicate the basalt to be extrusive rather than intrusive. Moreover, in both cases the basalt in question is superficial in position as compared with that shown in the deeper cuts of Union and Umptanum gaps.

Relative to the structural features of central Washington, then, the later and more detailed observations conflict with the results of earlier reconnoissance in these respects:

The mountain ridges described as monoclinal fault-blocks, tilted along lines of fracture, are found to be gentle anticlinal folds, with no evidence of faulting at any one of the several localities cited.

The assumption that lateral pressure had no part in this deformation is opposed by the structure section which shows compression, as well as by the occurrence of overturned strata on the sides of one of the synclines.

The hypothesis that igneous intrusions produced the deformation rests upon field evidence, which impresses the later observer as wholly inadequate.

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